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EXPLORING BOOST PHASE INTERCEPT CONCEPTS FOR THEATER MISSILE DEFENSE

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PREFACE

This report presents a preliminary exploration of concepts for implementing a boost phase intercept capability as part of theater missile defense (TMD). The material is intended to provide members of the arms control community with information in regard to the potential performance of long range (400 n mi) and short range (100 n mi) interceptor concepts and an indication of their basing schemes. The purpose of each of the concepts is to counter ballistic missiles of third world countries before multiple payloads can be dispersed, thus preventing damage to allies, friends, and armed forces of the U.S. This analysis, though limited, illustrates important characteristics of boost phase intercept concepts and is intended to provide the basis for further discussion of theater missile defenses and policy implications that may emerge in the future.

This report should be of interest to members of the arms control community, defense officials, and others concerned with national security aspects of theater and strategic ballistic missile defenses.

For those readers who want to gain an insight into boost phase interception concepts but not delve deeply into details, they should read the introduction, scan over the initial portions of each chapter, and then finish with the overview and observations. Comments, discussion, and suggestions should be directed to the author.

None of the material contained in this report should be construed to represent the official views of the U.S. Arms Control and Disarmament Agency, the Department of Defense, or any other organization within the U.S. Government. The views are solely those of the author.

CONTENTS

ACKNOWLEDGEMENTS

The author wishes to thank S. Mullen, G. Johnson and R. Batcher of ACDA/IVI for their support and thoughtful comments on the material presented in this report. The author is indebted to Glenn A. Kent of the Rand Corporation for the opportunity to review and discuss at length an early draft of his paper, Controlling Instabilities Caused By Rogue Governments (Strategic Stability in the Post-Cold War World and the Future of Nuclear Disarmament, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1995).

INTRODUCTION

The purpose of this report is to examine some concepts of intercepting hostile rockets during their boost or powered flight phase. The focus of this report is on ballistic missiles possessed by third world nations that might become involved in conflict with allies or nations friendly to the United States. The Department of Defense, through their Ballistic Missile Defense Organization (BMDO) is conducting intensive efforts to design various systems for theater missile defense (TMD). This report was prepared to provide an independent view of a few boost phase intercept concepts.

The motivation for examining boost phase interception concepts is clear. Third world nations may develop or possess dangerous toxic biological or chemical compounds, often referred to as the poor man's choice of weapons of mass destruction. When carried in a single warhead on a ballistic missile, these compounds may not cover a very large area. As an alternative, many warheads, as many as 40 or more sub-munitions, might be carried on ballistic missiles to provide area coverage on targets such as cities, supply bases, port facilities, air bases, troop concentrations, or other area targets. Such sub-munitions could be dispersed at the end of the powered flight of a ballistic missile or a few seconds later. Dispersal of sub-munitions during this phase of missile fight would involve the least expenditure of energy, and might be accomplished with very simple systems (spinning the sub-munition container, or use of pre-loaded springs). Terminal defense systems would be overwhelmed by the large number of payloads dispensed by a few ballistic missiles. Boost phase interception against such missile systems seems attractive since the number of interceptors needed to negate such a threat would be much smaller than would be needed in a terminal interception scheme.

The concepts examined in this report should be considered as being in the formulation stage with some additional information that could be useful during the definition phase of each concept. The formulation phase involves setting priorities and general characteristics of a concept. The definition phase involves providing design details for interceptors, their platforms, the command and control arrangements, and the target aquisition systems needed to provide a theater missile defense capability that lies within the state of technology and funding available when full scale development is approved. In this report, we shall examine what is needed, and provide some illustrative designs that are used to highlight potential problems and prospects for the future. We shall not provide enough detail to establish concept definition in its fullest sense.

The concepts examined in this report will include several approaches to interception capabilities during the boost phase of

short range ballistic missiles. The first chapter will be devoted to defining "the threat." Subsequent chapters will provide details concerning trajectories and some exemplary interceptor characteristics. These chapters will cover surface based and air based interceptors with long ranges that would provide the capability to stay outside of the area of hostilities. A subsequent chapter will address the possible use of unmanned aerial vehicles (UAV) or remotely piloted vehicles (RPV) to carry and launch interceptors over the immediate area of hostilities.

Long range boost phase interceptors designed for theater missile defense could be used for other purposes. One application of a surface based interceptor could be to attack sea launched and intercontinental ballistic missiles (SLBMs and ICBMs) during their boost phase. Russians are sensitive to this issue.

Interceptor warheads that fail to engage or miss their ballistic missile targets can travel great distances beyond the intercept point. Even if the warhead were destroyed by a high explosive charge should it miss, the debris and its destination may be a cause for concern. A number of instances of this problem will be examined.

Finally, an overview and some observations will be presented. Comments will be made concerning some of the issues not discussed in the body of this report. In this report, the primary emphasis will be on interceptor performance in terms of speed, reach, operational area, and coverage. In this preliminary exploratory effort, issues related to command and control, target detection, target tracking, target designation, kill probabilities, and kill assessment are not addressed.

POTENTIAL BALLISTIC MISSILE THREATS

Ballistic missiles have been and are proliferating throughout many countries in the third world. Some missiles have been purchased from major producers and others have been developed indigenously. Several references [1,2] provide an appreciation of the extent of present proliferation and future possibilities. These sources indicate the ranges, coverages, and countries of interest. Detailed design characteristics are more fully covered in other unclassified documents [3,4]. In this report we consider four potential ballistic missile designs: the SCUD-B, the Al Husayn, the Dong Feng-3, and a generic rocket using solid propellants. None of these designs are fully described and the author has inferred what may be missing to provide enough detail to estimate powered flight trajectories for each example.

Examples of ballistic missile characteristics used in this report are based on many assumptions. These assumed characteristics are displayed in Table 1.

Table 1
ASSUMED BALLISTIC MISSILE CHARACTERISTICS

	SCUD-B	Al Husayn	DF-3	SOLID
Gross weight (lbs)	13889	15432	140969	20262
Fuel weight (lbs)	8252	10605	120600	15532
Specific impulse (sec)	300	300	300	280
Thrust (lbs)	22222	24691	229075	60786
Base area (sq ft)	6.7	6.7	42.8	8.3
Nozzle exit area (sq ft)	1.2	1.2	11.5	3.0
Payload (lbs)	2100	1100	4735	2200
Range (n mi)	160	325	1430	670

All of these missiles are single stage rockets. The numerical values were inferred so as to result in the ranges cited in source documents. The time of powered flight is a function of the amount of fuel, the specific impulse, and most importantly the initial thrust to weight ratio. The Dong Feng-3 (DF-3) was the only missile where thrust was provided in open source literature. The SCUD-B and Al Husayn values were based on the reported initial thrust to weight ratio of the DF-3 and conventional missile design practices. The specific impulse and nozzle exit areas were inferred or based on estimates of normal design practices [5]. Fuel weights are estimates based on guesses regarding structural fractions. All parameters may be somewhat in error, but do provide a basis for calculations of powered flight trajectory examples.

One parameter of particular interest in examining boost phase interception capabilities is the time of powered flight of missile in question. The time of powered flight is sensitive to a number of assumptions, but is most sensitive to the initial thrust to weight ratio. Other parameters having influence include the amount of fuel expended and the specific impulse of the propellants used. Figure 1 shows the ratio of the powered flight time to specific impulse as a function of the initial thrust to weight ratio, assuming a constant thrust and no losses due to drag or gravity. From this graph it is clear that any errors in assumptions could have a significant effect. It is also clear that one way of avoiding or lessening the possibility of intercepts during boost phase of flight would be to increase the initial thrust weight ratio. In Table 1, the initial thrust to weight ratio for the DF-3 was 1.625. This value is within the normal design range for missiles using liquid propellants. This same initial thrust to weight ratio was applied to the assumptions for the SCUD-B and the Al Husayn. Normal design practices for missiles using solid propellants, such as Minuteman, would result in initial thrust to weight ratios between 2.5 and 3.0. The generic solid rocket design shown in Table 1 is based on the assumption that this parameter is set to 3.0. When trajectories are simulated, the effects of the atmosphere will cause reductions in thrust when the missile is near the earth's surface. Such reductions are accounted for by the method used to estimate powered flight trajectories.

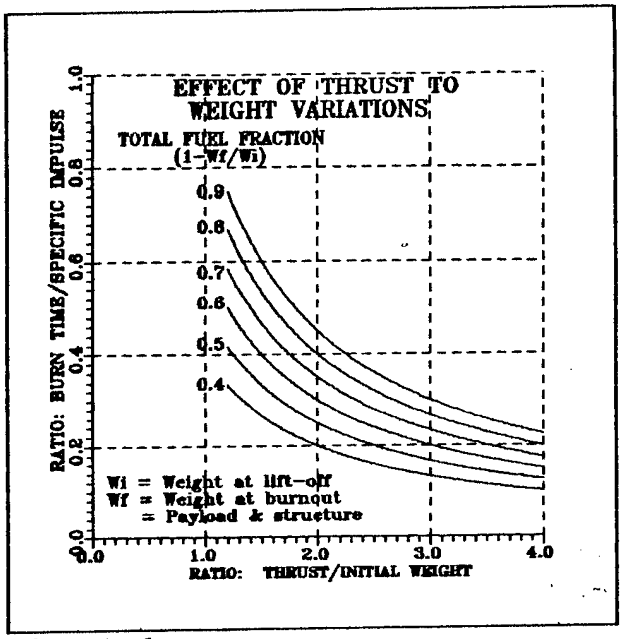

Figure 1

Powered flight trajectories based on the assumptions of Table 1 were calculated using a three degree of freedom point mass method [6]. Figure 2 shows the profiles of each ballistic missile type and indicate the time of powered flight. To illustrate all trajectories, each has been set apart by a few miles in the downrange direction. All of the trajectories shown are near the minimum energy solution, i.e. the ground range from launch to warhead impact is nearly maximum. The times of powered flight or burn times vary between 70 sec and 150 sec. The longest time of powered flight is that of the DF-3 and the shortest is the example labeled SOLID. The solid rocket used here is somewhat similar to one stage of the Minuteman ICBM. The

initial thrust to weight ratio is 3, about twice as high as normally used with liquid propellent missiles. The higher value of thrust to initial weight results in a shorter burning time.

The SCUD-B powered flight trajectory shown in Figure 2 has a burn time of the propellants is about 110 sec, and could vary somewhat depending on the assumptions made. A ten per cent variation in initial thrust to weight ratio could decrease or increase the time of powered flight by about ten per cent. The Al Husayn missile was developed in Iraq and is an example of an upgraded version of the SCUD-B. It has a somewhat longer burn time, about 130 sec, based on the assumption that it has more fuel than the SCUD-B. The Dong Feng-3 (DF-3) missile was built by the Chinese, and one version of it is deployed in Saudi Arabia with a large conventional warhead. This missile is larger and has a longer range than the previous two examples. The DF-3 has a burn time of almost 150 sec. Finally, a generic solid rocket is offered as an example of a missile with a shorter burning time, about 70 sec. Such a design could stress the performance of boost phase intercept systems if they were designed to attack liquid propelled missiles.

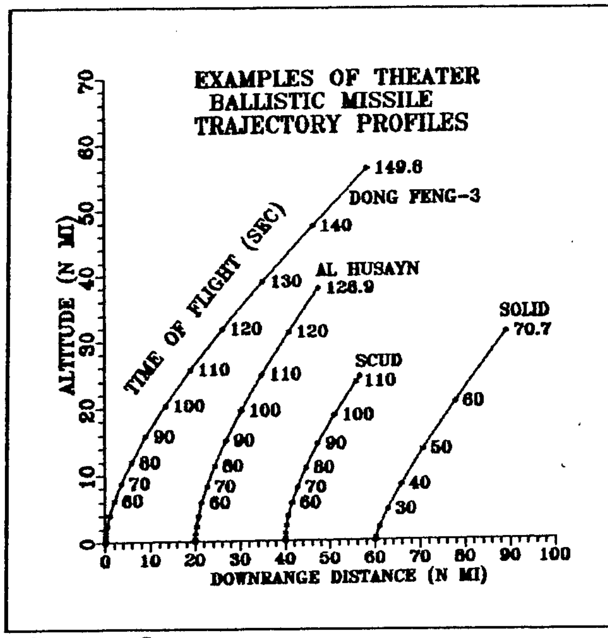

Figure 2

There are other missiles being built or already deployed in a number of third world nations. The missiles selected for study in this report represent a variety of times of powered flight. Very short range missiles could have shorter times of flight, but will not be considered here.

LONG RANGE INTERCEPTORS

If the platform carrying interceptors cannot infringe upon the territories of interest, then the range of a boost phase interceptor (BPI) will be determined by geographical constraints. In this chapter, we consider sea based interceptors and those carried by aircraft.

For countries that might be able to launch ballistic missiles, Iraq and Iran represent a challenging example. We use this example to estimate the minimum interceptor range neeeded for complete coverage. Figure 3 provides the coverage from a few suggested platform locations for an interceptor with an 800 km range. The locations of interceptor launchers used in this figure are near Antioch, the upper reaches of the Persian Gulf, east of the straits of Hormuz, and the southeast corner of the Caspian Sea. This latter base would be needed to provide coverage of the northwestern and northeastern areas of Iran. Such coverage is based on the assumed cooperation of the Russians. If Russia were not to cooperate in such a venture, then coverage of the northwestern part of Iran could be provided by a ship based in the easternmost part of the Black Sea, but there would be no coverage of northeastern Iran. This example of coverage would also apply to aircraft platforms if they were not to overfly Iran or Iraq. Aircraft overflying Turkey and Pakistan could provide substantial coverage if the interceptor range is 800 km (430 n mi). We define a "long range" interceptor as one having a range greater than 400 n mi. This value will be used to estimate the average velocity needed to permit interceptions to take place before the missiles reach their burnout flight times.

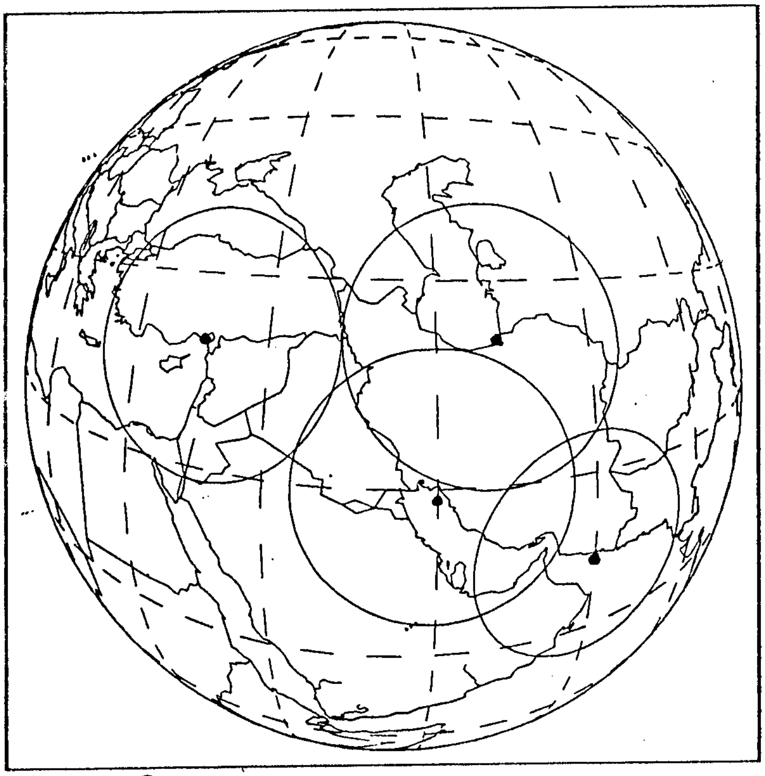

Figure 3

The long range interceptor must get to its target, a missile, before the missile reaches its burnout condition. On average, the interceptor must travel about 800 km (430 n mi) in about 100 sec. The average velocity must be about 8 km/sec or 4.3 n mi/sec. If the powered flight time of the target missile is somewhat longer, then a lower average velocity may be acceptable. To meet the need of a rapid reaction, the interceptor must have a very high acceleration during its boost phase of flight. In this discussion we have assumed an initial thrust to weight ratio for each interceptor stage of 40 g's, or about 1388 ft/sec^2. The design formulated as an example is given in Table 1. This interceptor design may be launched from sea level or from an aircraft flying at an altitude of 7 n mi. The time of powered flight is about 14.5 sec, but burnout velocity will vary depending on the launch mode. High density solid propellants are assumed, and structural weights will hopefully be sufficient to withstand the high accelerations involved. The entire design is based on a final step payload weight of 200 lbs.

Table 2 - Long Range Interceptor Parameters

	Step 1	Step 2	Step 3
Gross Weight (lbs)	10286	2857	755
Fuel Weight (lbs)	6774	2258	472
Specific Impulse (sec)	285	285	285
Thrust (lbs)	433045	114269	30207
Base Area (sq ft)	3.82	1.84	1.32
Exit Area (sq ft)	3.82	1.28	0.34
Payload (lbs)	2857	755	200

The powered flight trajectories for this suggested interceptor design are shown in Figure 4. The times of staging are 4.46 sec and 10.09 sec. Burnout occurs 14.54 sec after launch. The short times of powered flight are a result of the high thrust to initial weight selected for a rapid reaction capability. In the surface launched mode (the lower curve), gravity and drag losses are fairly high and the burnout velocity is just over 25,000 ft/sec. For the air-launched mode (the upper curve), the burnout velocity is just over 30,000 ft/sec because losses due to drag and gravity are lower than in the sea-launched mode. The trajectory employed for the sea-launched interceptor has been somewhat lofted in an attempt to keep aerodynamic heating within bounds. Trajectory analysts may wish to exercise their expertise and suggest other methods for keeping within dynamic pressure and heating constraints. The design shown here is intended only for illustration.

To estimate the time of flight envelopes from launch to intercept, many powered flight and coasting trajectories were calculated using a three degree of freedom point mass program called COMET [6]. The results of these trajectory calculations are shown in Figures 5 and 6 indicating flight time from the launch of the interceptor. Figure 5 illustrates time of flight and trajectory contours for sea based interceptors. Figure 6 shows contours for air launched interceptors. These contours can then be compared to the trajectories of the threatening missiles to find approximate solutions in terms of timing, distance, and altitude for various intercept geometries.

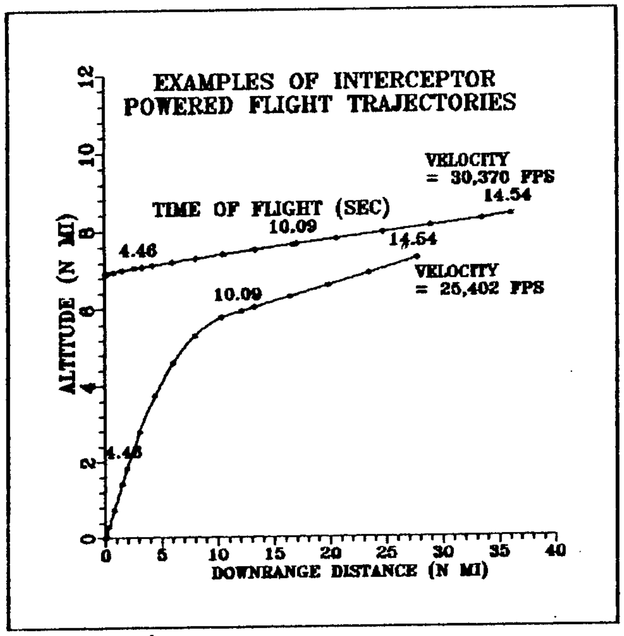

Figure 4

Trajectories for the threatening missiles are based on the assumption that the hostile missile is launched from a position that is some distance from the interceptor launch point. Contours of the interceptor trajectories permit examination of where the intercepts might take place (range, altitude) and some time delays can be considered. If superb intelligence is available, the interceptor could be launched simultaneously with the launch of the hostile missile, a most favorable case. Otherwise, some sensor system would be used to detect the launch location and the interceptor launched as quickly as possible. Extended delays might make boost phase

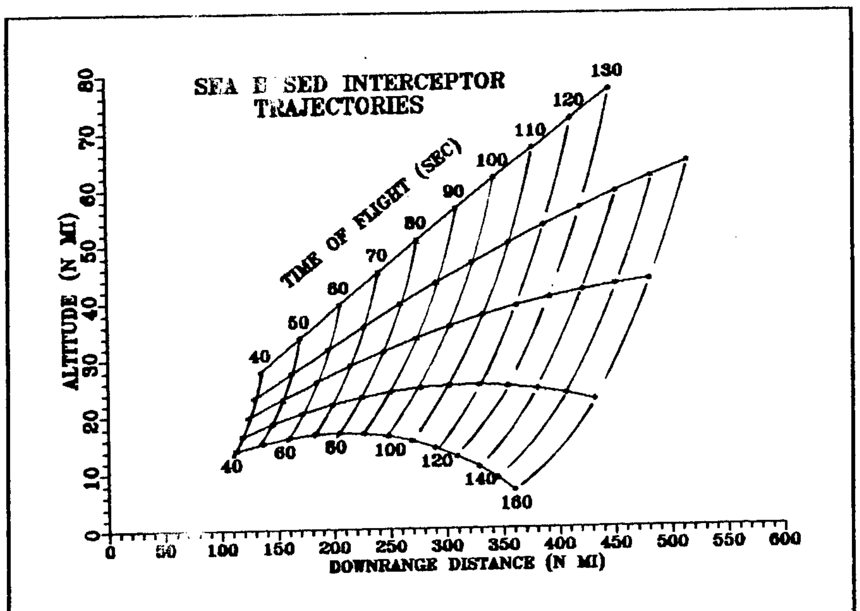

Figure 5

interception a non-viable concept, or raise the issue of overflying hostile territory with a manned aircraft carrying a number of large (10,000 lb) interceptors. Figure 7 shows the powered flight trajectories of the attacking ballistic missiles, or targets. Each launch point is separated somewhat so that the trajectories are clearly presented.

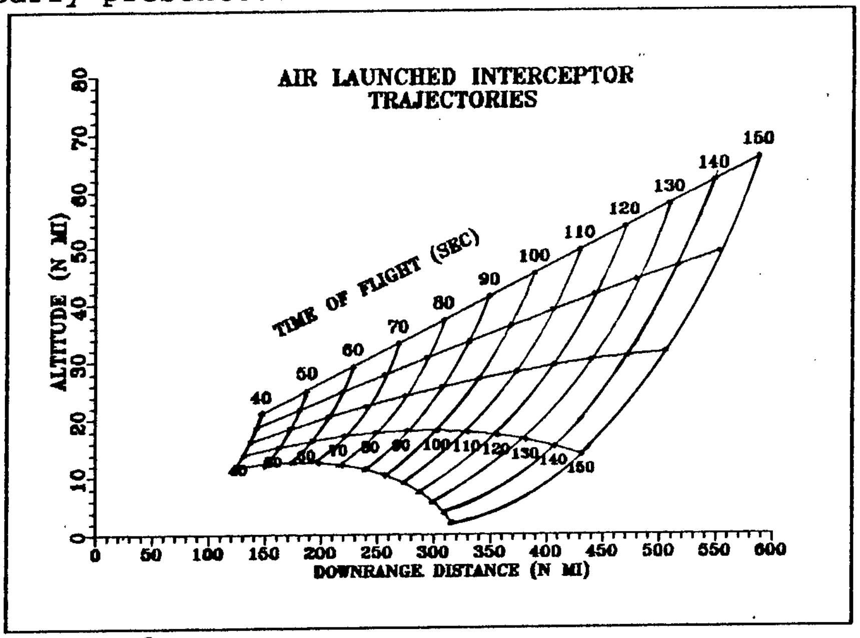

Figure 6

Solid rocket designs with higher initial thrust to weight ratios might emerge in the future. Such rockets have many operational advantages over liquid fueled missiles. If a boost phase interceptor were to be deployed, such a missile could provide some capability in countering early interceptions. If the boost phase interceptor were able to engage the payload after burnout, then the payload might be negated, but the debris would continue on a ballistic trajectory toward its target. The debris would probably be spread out over a large area and might not cause damage to the intended target, if one believes that the debris would become overheated during its reentry into the atmosphere. In this analysis we limit our consideration to interceptor engagements which take place before burnout.

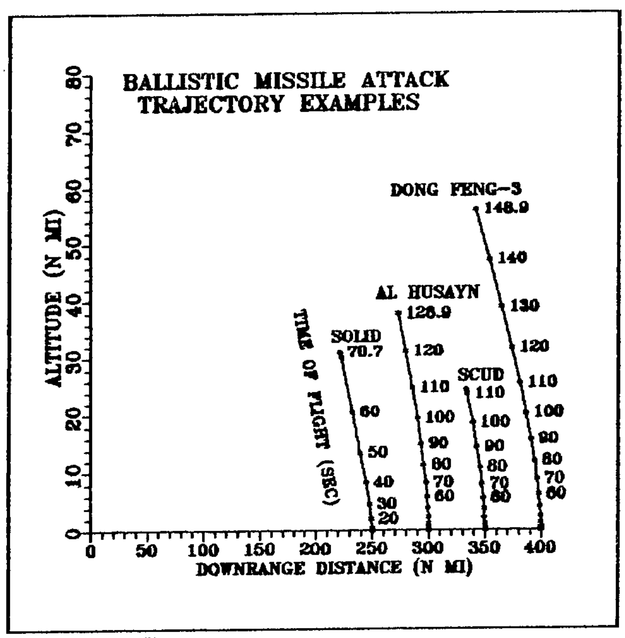

Figure 7

What are the distances between the launches of an interceptor and a target missile that might be achievable? What would be the effect of delays in launching the interceptor? These

questions lead into an analysis that utilizes the information developed earlier illustrating the trajectories of both interceptors and hostile ballistic missiles. The maximum separation distance between the interceptor platform and the ballistic missile launcher would occur if intelligence was perfect, i.e., the interceptor was launched at the exact same time as the hostile missile. If such perfection could not be achieved, then time delays in launching the interceptor would tend to shorten the separation distance. Such time delays could result from failures to immediately detect a missile launch, failures to quickly pass targeting information along to the interceptor platform, and failures in immediately launch interceptors on receipt of targeting information.

The combination of performance characteristics of surface launched interceptors compared to the various ballistic missile trajectories indicate the maximum intercept distance possible. The effects of time delays in tactical warning are indicated as a loss in intercept engagement range in Figure 8. Delay times are measured from the time of launch of the offensive ballistic missile. Missiles with a long time of powered flight, the DF-3 in these examples, could be intercepted at ranges of 400 n mi even though delays in interceptor launches might be as high as 40 sec. In the extreme, interception of solid propelled missiles could call for a range between interceptor launcher and a ballistic missile launcher of about 130 n mi if a time delay were about 40 sec. If solid rockets do become common in later time frames, then sea basing of boost phase interceptors of the type described here would be able to cover only a small fraction of the hostile territory (Iran and Iraq in the present example).

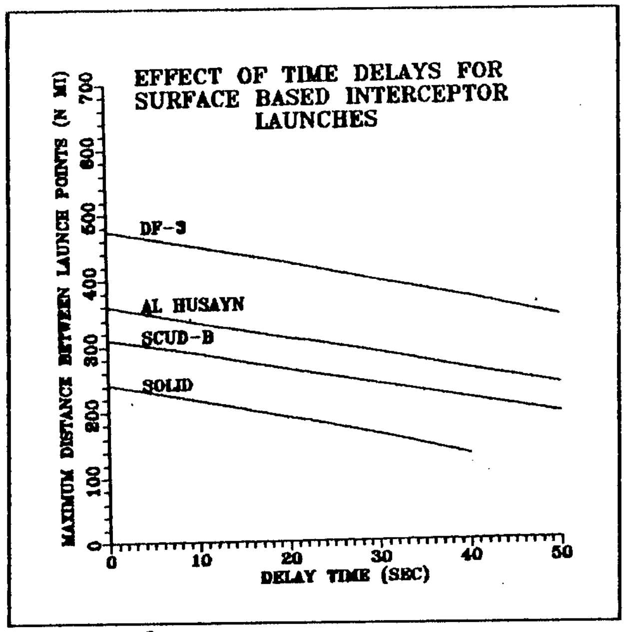

Figure 8

An increase in distance between interceptor and ballistic missile launch platforms could be achieved if air-launched interceptors were employed. Figure 9 shows the maximum range between interceptor and ballistic missile launchers as a function of delay time for air-launched boost phase interceptors. In the best case for the defensive system the Al Husayn and DF-3 missiles could be engaged even with time delays up to 40 or 60 sec, respectively, based on a minimum engagement range of 400 n

mi. Interceptions of SCUD missiles would be marginal, at best, with no time delays. Interceptions of solid propelled missiles could not be attempted unless the aircraft intruded well into hostile territory to shorten the engagement range to 290 n mi or less, depending on delay times.

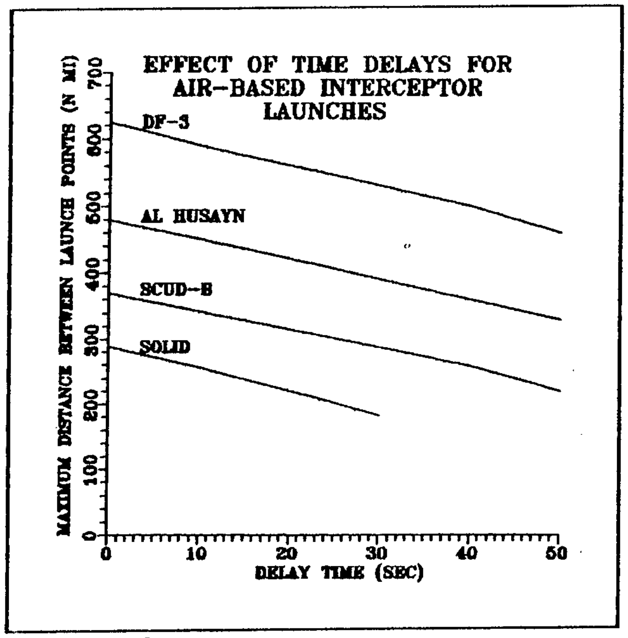

Figure 9

The long range interceptors discussed in this chapter are very sensitive to variations in the threat. If the time of powered flight of a ballistic missile is shortened, or if a new missile with a shorter burning time is deployed, then the velocity needed to perform boost phase intercepts increases dramatically for a given standoff range, in this case 400 n mi. Figure 10 indicates this trend as a function of the time of powered flight for different standoff ranges. While shorter burn times tend to drive up the interceptor velocity needed, the weight of the interceptor will increase in an exponential fashion with linear increases in velocity. Thus, another way to cope with shorter powered flight times is to get closer to the launch platform of the ballistic missile. Operational constraints may rule out such a solution.

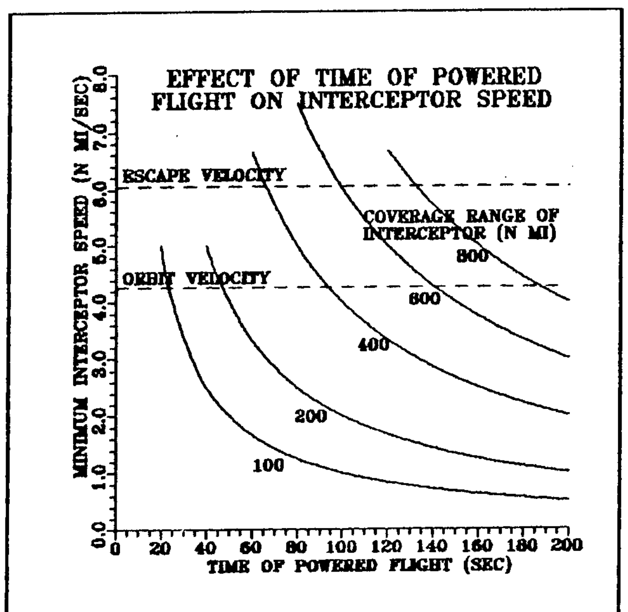

Figure 10

As a result of the above analyses, we conclude that the high performance boost phase interceptors described in this report may not be able to cope with some future types of ballistic missiles. The performance of air-launched interceptors was somewhat better than those based at sea. Keeping aircraft flying for extended periods of time might prove to be more difficult or costly than keeping a ship on station at sea. While either mode of basing would provide the capability of intercepting DF-3 and

Al Husayn missiles (at least in principle), neither system could adequately cope with a future solid propelled ballistic missile if either Iraq or Iran were to develop them. Such interceptors would have application to other areas of concern, such as North Korea or other areas where the intercept engagement ranges fall within the geographic bounds of the area. The engagements that were examined in Iraq and Iran were made possible by proposing to build a very high velocity interceptor. The burnout velocities of the systems examined were between 25,000 and 30,000 ft/sec. As we shall see in a later chapter, these systems might have provocative applications against other kinds of ballistic missiles.

SHORT RANGE INTERCEPTORS ON RPVs

In this chapter, short range interceptors carried by stealthy remotely piloted vehicles (RPV) are considered for performing boost phase intercept of ballistic missiles. Such concepts are being considered by Israel. Other RPVs in the design and test phase in the U.S. might also be used for this mission [7]. Other reports in the professional press [8] also indicate some of the performance parameters of the Tier 2+ vehicles. Although yet to be tested by the U.S. Department of Defense, Tier 2+ vehicles are designed to fly at 65,000 ft with a payload capability of 2000 lbs. The Tier 3- vehicle, Darkstar, is being designed to carry a 1,000 lb payload for 12 hrs at 50,000 ft. The Darkstar is a stealthy vehicle. These vehicles may not be aircraft designed to carry short range boost phase interceptors, but they represent a new family of low cost long endurance RPVs now emerging utilizing new technologies and austere design constraints which could lead to vehicles that carry weapons rather than reconnaissance sensors.

The concept explored here consists of many RPVs operating on station over hostile territory carrying interceptors. For now, we assume that these RPVs are fully survivable in a third world air defense environment. Ultimately, the endurance actually achievable and the payload capabilities would determine the number of vehicles and support equipments to be procured.

The number of interceptor stations needed to cover a large area, such as Iraq, Iran, or a combination of the two has been selected for purposes of this analysis. The area involved is large, but may provide insights as to numbers of vehicles needed to provide coverage, if no intelligence information regarding the location of hostile missile launchers is available. Figure 11 shows the number of stations needed to provide complete coverage of Iraq, Iran, or the combination of both nations as a function of the interceptor range. To provide coverage, but to keep the number of interceptor stations within reason, we have selected an interceptor range of 100 n mi. About 20 stations will provide coverage of both countries for a 100 n mi range interceptor.

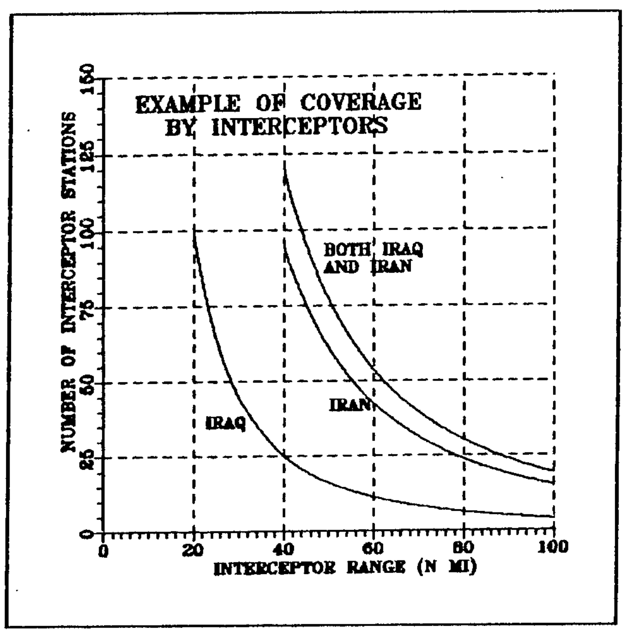

Figure 11

The average speed of the interceptor depends on the time of flight of the threatening ballistic missiles. Nominally, we have selected a flight time of about 120 sec. Under this assumption, the average speed of the interceptor should be about 5000 ft/sec. Two interceptor designs were examined. One has a payload of 200 lbs, and the other has a payload of 100 lbs. Some might argue that if a 200 lb payload vehicle could perform intercepts at a range of 400 n mi (such as discussed earlier), then at shorter ranges a 100 lb payload might have the capability of acquiring and destroying targets at 100 n mi ranges. The design parameters of the two vehicle options are given in the following table.

Table 3 - Assumed Short Range Interceptor Characteristics

Versions	#1	#2
Gross Weight (lb)	524	218
Fuel Weight (lb)	227	94.4
Specific Impulse (sec)	280	280
Thrust (lb)	20960	8720
Base Area (sq ft)	0.785	0.382
Exit Area (sp ft)	0.25	0.15
Payload (lb)	200	100
Launch Altitude (n mi)	10.7	10.7
Ideal Velocity (ft/sec)	5100	5100
Thrust to Initial Weight	40	40
Structural Fraction	0.3	0.2

The first interceptor is similar to the Maverick ground attack missile, except for its thrust to weight ratio. The second version has a smaller payload and a more efficient structural fraction. In this analysis, we are able to sidestep making a choice between them, since both have nearly identical flight trajectories. Both have very high thrust to initial weight ratios to provide very short burning times, about 3 sec. If version #2 is a realistic design, then it would be preferred since each platform could carry more firepower. The short burning time is a result of the high

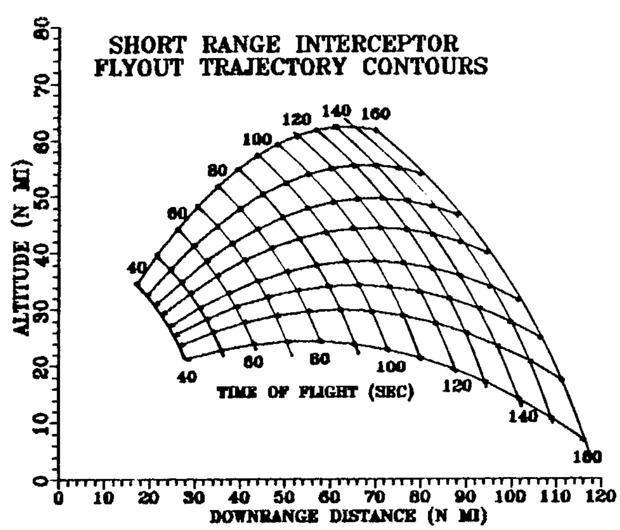

Figure 12

thrust to weight ratio and leads to interceptor missiles with a rapid reaction capability.

The performance of short range interceptors will be critical in evaluating their effectiveness against hostile ballistic missiles. Many flight trajectories have been calculated and the results are displayed in Figure 12. The altitude of the interceptor is shown as a function of its range with the time of flight (measured from launch) as the parameter. The asterisks indicate the data points from a variety of trajectory calculations. The velocity at burnout for all trajectories is nearly the same, about 5170 ft/sec.

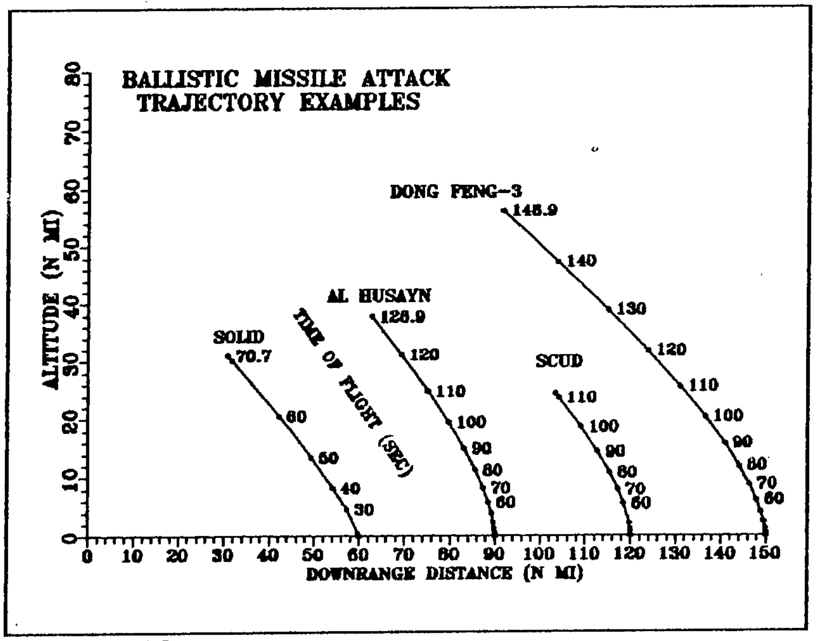

Figure 13

The engagement ranges for the short range interceptors are estimated by overlaying the time of flight contours of the interceptor with the time of flight contours of each hostile ballistic missile. The flight profiles of each of the examples of third world ballistic missiles are again shown in Figure 13, but to a different scale. The launch points for each missile have been separated somewhat for clarity. The ranges to each assumed launch point are equal to or less than 150 n mi to provide the perspective associated with short range interceptors carried by RPVs. These trajectories are then compared to the interceptor capabilities to provide

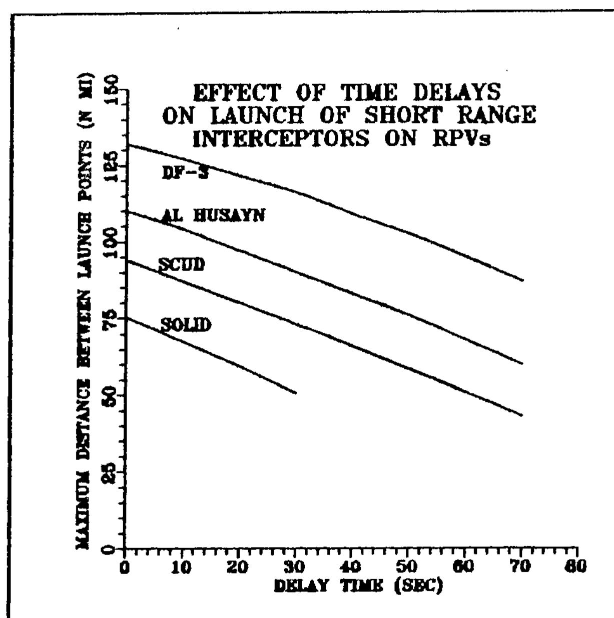

Figure 14

estimates of the effects of delays in launching the interceptors. Using this procedure, the engagement ranges are found as a function of delay time in the launch of the interceptor missile. Figure 14 shows the results based on the assumption that interceptor platforms are assigned to ballistic missiles flying in their direction, the most favorable case. If an interceptor were to be assigned to attack a ballistic missile headed at right angles or directly away from the interceptor platform, then the engagement range would be smaller than indicated in this figure. The most favorable engagement ranges are between 75 n mi for countering the solid propelled missile to 127 n mi to attack the Dong Feng-3 during powered flight. These engagement ranges decrease as the interceptor launches are delayed.

The effects of delays in launching an interceptor will have effects on the actual engagement range against each type of ballistic missile. With a time delay of 30 sec, the engagement range against a missile using solid propellants would be reduced to about 50 n mi. Without information concerning the launch locations of the ballistic missiles, the number of platforms needed to cover all of the territory of Iran and Iraq would increase from 20 to about 35 (no time delay) to about 75 (time delays of 30 sec). Thus, accurate information regarding the launch locations of hostile ballistic missiles would be helpful in limiting the number of launch platforms needed to intercept them. If hostile third world nations continue to employ older liquid fueled missiles such as Scud, or rely on improved longer range versions of these missiles, then the number of platforms needed would not be as great as if they turned to the technology associated with solid fueled ballistic missiles.

The short range interceptor platforms operating over hostile territory offer one distinct option not possible for the longer range interceptors considered earlier. The ground rule for platforms carrying long range interceptors was that they not operate in or over enemy land masses. The short ranged interceptors must operate over enemy territory, and their platforms can be directed to areas where ballistic missiles might be launched, IF intelligence information as to launch locations can be provided. Without such intelligence, there would have to be more interceptor platforms if Iran and Iraq were to develop a solid propelled missile of the type considered here.

In examining the use of RPVs to carry short range boost phase interceptor missiles, we have concentrated on performance. There is one issue that will be paramount in deciding to deploy such a defense system -- the survivability of the interceptor platform. In this analysis, we have assumed that these platforms would be invulnerable because of their stealthy characteristics. Further analysis might show that such an assumption could be in doubt, and could have a significant influence on any decision to build or deploy such a system. The present discussion is limited

to exploring concepts, not to defining all of the detailed characteristics. Thus, there is an open question regarding the operational viability of boost phase intercept systems deployed over hostile territory. The results of other analyses of air defense systems of various nations may strongly influence decisions concerning whether or not RPVs with boost phase interceptor missiles will be a universal solution to negating ballistic missiles launched by rogue nations.

OTHER APPLICATIONS OF TMD BOOST PHASE INTERCEPTORS

The purpose of this chapter is to examine some incidental roles for boost phase interceptor platforms designed to counter theater ballistic missiles. Of particular interest are applications of the sea based long range interceptors, i.e. those designed to cover 400 n mi or more in about 100 sec.

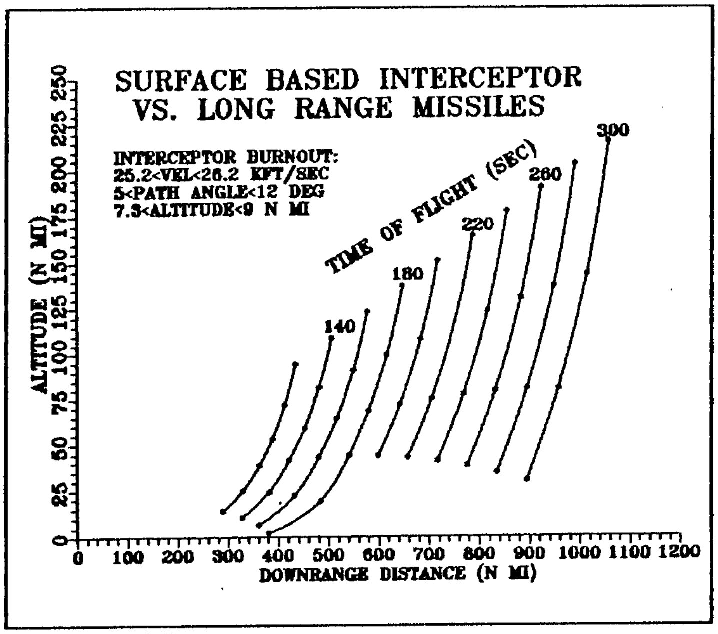

Figure 15

The interceptor designs described earlier in this report would have very high velocities at the end of powered flight. For interceptors based on surface or sea based platforms, this velocity is slightly in excess of 25,000 ft/sec, or near orbital velocity. The time of flight contours shown earlier were presented to indicate capabilities of intercepting short range ballistic missiles that might be acquired by third world countries. The interceptor payloads would coast for considerably longer times of flight than indicated in the previously developed trajectory envelopes. Thus, these interceptors might have boost phase capabilities against longer burning ballistic missiles at much greater engagement ranges than considered earlier in this report. Figure 15 indicates the much longer interceptor ranges involved when intercept times up to about 300 sec are considered.

Alternative missions for theater missile defense systems intended for boost phase intercepts could include other targets related to strategic capabilities. These other targets could include sea launched ballistic missiles (SLBM), and ICBMs (solid or liquid propelled). In this chapter we examine the sea based boost phase interceptor capabilities against each of these targets.

The trajectories for various strategic ballistic missiles were calculated based on information available in the the open literature. One important parameter in making these calculations is the range of each type of missile. From the range, the analyst can infer the final velocity needed, and a rough estimate of velocity losses, depending on the type of propellant, whether solid or liquid. Other inputs from data available in the open

literature will supplement such estimates. Table 4 outlines the pertinent rocket performance factors for three different types of strategic missiles. The first is a sea launched ballistic missile (SLBM) similar to versions of Trident. It is a two stage solid propelled missile with a range of about 4000 n mi. Lighter payloads are possible and would result in longer ranges. The second missile is a three stage solid propelled ICBM similar to the SS-25 or Topol-M. It is assumed that its range is 6000 n mi. The third missile is a two stage ICBM utilizing storable liquid fuels. If third world countries attempt to develop an intercontinental capability, they might choose either a liquid or solid fueled alternative. Currently, the U.S. and Russia are tending to emphasize solid propellant ICBMs for various operational reasons such as quick reaction and long storage life.

Table 4 - Examples of SLBM and ICBM Design Estimates

	SLBM (Solid)	ICBM (Solid)	ICBM (Liquid)
Launch Weight (lbs)	130070	77800	223200
Payload Weight (lbs)	6000	2600	7500
Number of Stages	2	3	2
Specific Impulse (sec)	260-280	260-280	320-340
Structural Fraction	0.15	0.15	0.08
Range (n mi)	4000	6000	6000

The trajectories derived from the parameters describing each missile type are shown in Figure 16. The viewpoint is that of the operator of the interceptor platform. The altitude of each type of missile is shown as a function of the range from an assumed interceptor platform is shown with the missile time of flight indicated as a parameter. Solid propelled missiles have times of powered flight between about 170 sec (SLBM) and about 200 sec (ICBM). For a two stage liquid fueled ICBM, the time of powered flight could be about 300 sec. The times of powered flights for these missiles is much greater that those of theater ballistic missiles presented earlier in this report.

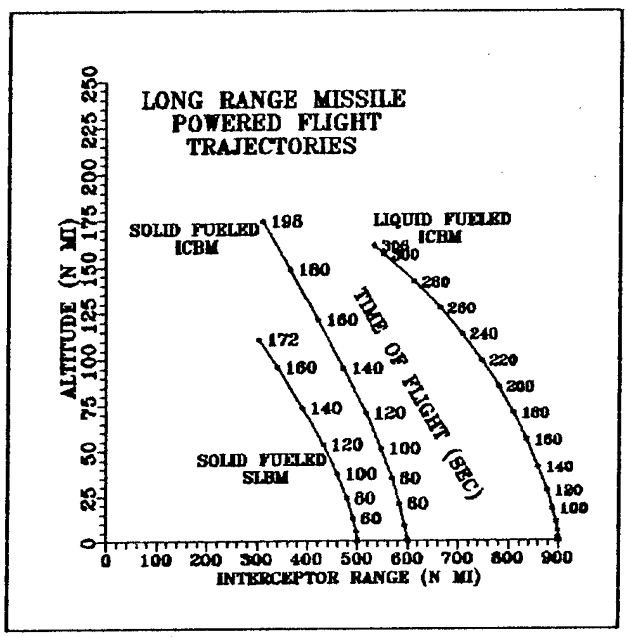

Figure 16

If the sea based interceptors were used against strategic missiles, then there would be some time delays involved in launching the interceptors. Such delays could be attributed to delays in launch detection, relay of the information to command centers, delays caused by failure to act immediately to such information, delays in transmitting information to those commanding the sea based forces, and finally delays involved in implementing firing orders against the strategic missiles in flight. Figure 17 indicates these effects for the strategic missiles considered in Table 4. The effective engagement ranges are much larger than those considered earlier. The increased capabilities could have implications not intended in the design of a theater missile defense system.

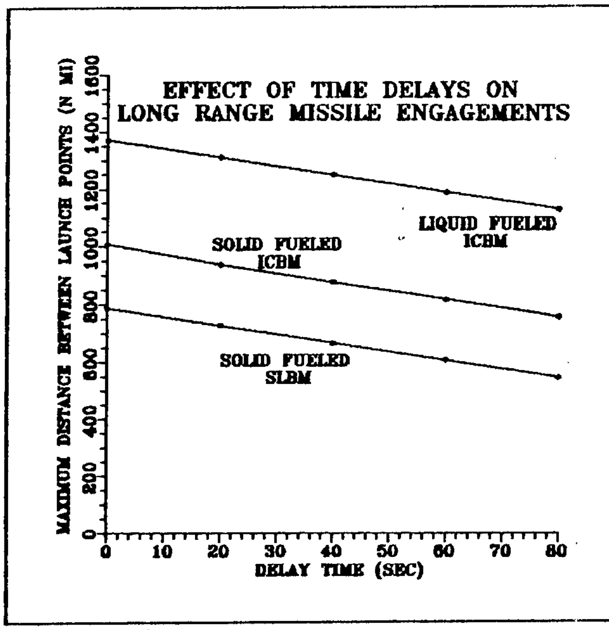

Figure 17

Russian TMD and U.S. Strategic Forces

If the Russians were to design, develop, and deploy a system such as described earlier, then they might be able to subject a significant portion of the U.S. strategic deterrent force to a new threat. Two sea based interceptor platforms deployed in the North Atlantic could possibly cover the deployment of Trident submarines and their missiles. If the SLBMs were launched, the interceptors could engage them. In addition, the location of the submarine launching the SLBMs might become known to the Russians, and they might implement measures to attack the submarines. In this analysis, such possibilities are not covered, but are mentioned to illustrate some side effects of theater missile defense systems.

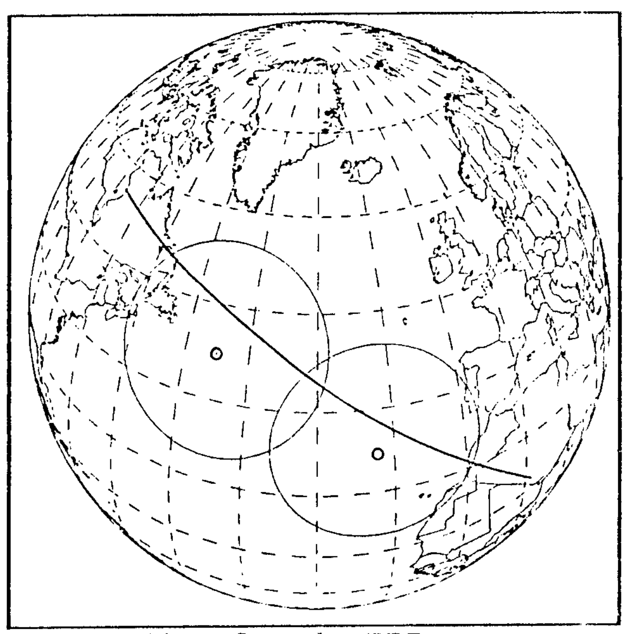
Figure 18 Atlantic BPI

Figure 18 indicates one possible deployment and coverage of two Russian ships in the North Atlantic for countering U.S. SLBM launches. The long diagonal line indicates a line 4000 n mi distant from Novosibirsk corresponding to the range of the Trident given in the open literature. With reduced payloads that will come into effect under START II, the Trident launch areas might be located to the south of this line. The actual location of Trident patrol areas is not known. The range of the boost phase interceptors considered here is large enough that two ships could cover a very large area, enough to be of concern to U.S. strategic force operations. Russian anti-submarine warfare technology of the future may or may not be capable of finding and tracking Trident submarines. If Russian ASW detection is good, but the localization is poor, then such information may still be of use to the Russians because of the large coverage provided by just a few ships. U.S. Navy personnel might argue that the Russian surface ships might be very vulnerable to attack by air, other ships, or attack submarines. The survivability of the Russian ships is beyond the scope of this report. The present discussion merely raises the issue of a potential impact of Russian TMD systems on U.S. strategic assets.

U.S. TMD and Russian Strategic Forces

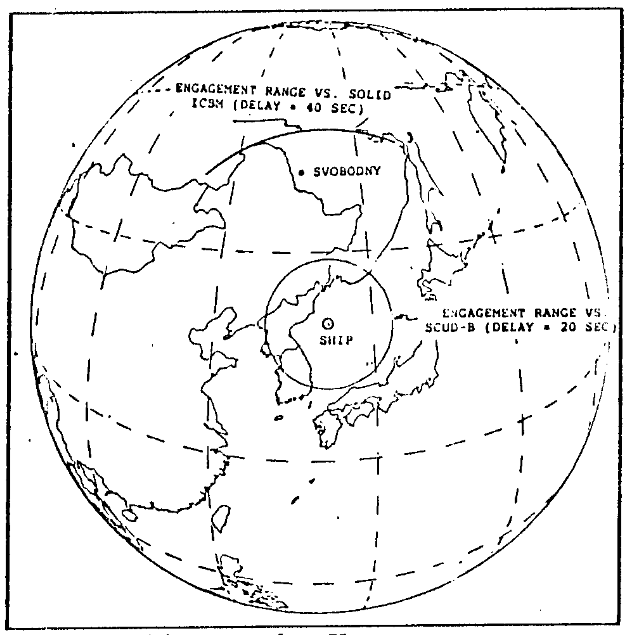

Figure 19 BPI in Korea

Some factions of the Russian government have expressed the opinion that theater missile defenses should not have boost phase intercept capabilities [9]. They are concerned that some of their strategic ICBMs could be countered in boost phase, thus negating some of their strategic nuclear capabilities. For example, if the U.S. were to deploy a ship with theater missile defense capabilities into the Sea of Japan to counter possible North Korean ballistic missile attacks on our Asian friends or allies, this ship might have unforseen capabilities. One of the Russian missile bases is located near Svobodny in eastern Siberia [10]. The distance between the ship and this base would be about 500 to 600 n mi, well within the engagement capabilities against solid propelled ICBMs of the type shown in Table 4 above. Figure 19 indicates the geography of the situation. Although the ship is positioned to counter SCUD launches from North Korea, the Russian interpretation of U.S.

interceptor designs could present a threat to Russian ICBMs based near Svobodny.

If the Russians were to retain some liquid propelled ICBMs and base them in silos formerly occupied by SS-17s, then these ICBMs could also come under fire by a so-called theater defense system employing boost phase intercept capabilities. For example, if two stage liquid propelled ICBMs were based at Kostroma, then they might be intercepted by U.S. platforms operating in the Norwegian or Barents Seas. For example, the distance between a ship operating just off the west coast of Norway and the missile base near Kostroma is about 900 n mi.

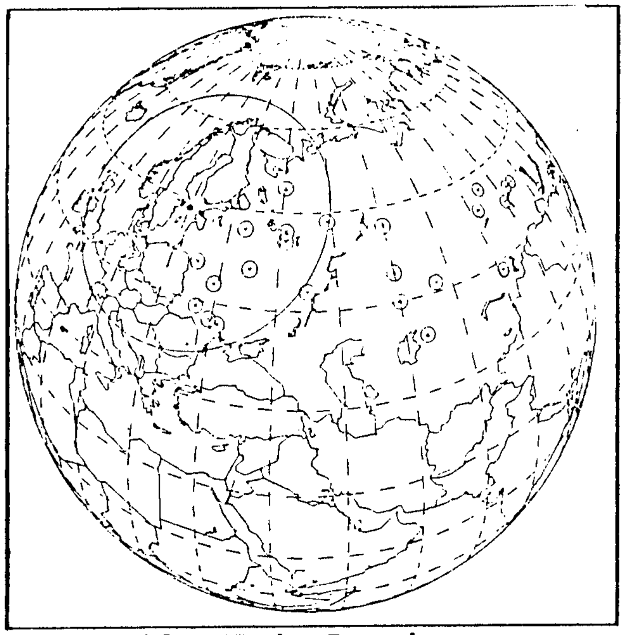

Figure 20 BPI in Russia

The forward basing of an American cruiser in the Baltic Sea, whether equipped with boost phase interceptors or not, could cause great concerns to the Russians. The boost phase intercept range of such a ship against Russian ICBMs is shown in Figure 20. The ICBM bases indicated in this figure were drawn from various sources [10,11,12,13]. Missile bases are shown by circles around an X. From this diagram, two points emerge. First, the coverage of boost phase interceptors could be of great concern to Russian military leaders. Second, U.S. Navy leaders might find it a bit tricky to send a large ship into the Baltic, especially if they are concerned with the survivability of the ship in close proximity to Russian naval and air force areas of operation.

From these examples, one can find objections to the deployment of boost phase intercept systems designed for use against ballistic missiles to cause concerns to both the U.S. and the Russians. The ship based interceptors could cause unintended concerns for both major powers. For the U.S., Russian ships at sea in the North Atlantic Ocean might have the capabilities to negate Trident missiles before multiple warheads and decoys could be deployed. For the Russians, U.S. ships in the Norwegian or Baltic Sea, or in the Sea of Japan, could have a similar capability against Russian SLBMs. Thus, it is the geography combined with the potential ranges of engagement that tend to catch the eye of planners in both nations. During a recent summit, leaders of both nations agreed that theater missile

defenses should not deployed in such a manner as to be able to counter the strategic forces of either side. This ground rule bounds the extent to which representatives can come to a common understanding and emerge with mutually agreeable delineations as to what types of ballistic missile defenses can be considered "strategic" as opposed to those which might be "tactical" or theater based.

A PROVOCATIVE SIDE EFFECT OF BOOST PHASE INTERCEPT

In previous discussions (Table 2), the sea based boost phase interceptor reached very high burnout velocities, about 25,000 ft/sec. At these velocities, the interceptor warhead would continue on a flight path that might have a side effect on nations near the theater of operations. While the warhead might present no direct threat to others, it may not be possible for others to discern the non-threatening aspect of the object headed their way.

An interceptor warhead continues on a free flight trajectory should it not be able to hit its target (a ballistic missile). In some cases, the geography may be such that the high velocity object intended for theater defense may cause great concerns to nearby nations with sensors which can detect and track satellites or ballistic missiles.

The launch of a boost phase interceptor against potential Iranian ballistic missiles serves to illustrate this important side effect of theater combat. If it is assumed that the Iranians were to launch ballistic missiles from the western part of their nation, and that these missiles were to be countered by U.S. boost phase interceptors in the Persian Gulf and east of the Straits of Hormuz, what might Russians perceive during and after such engagements?

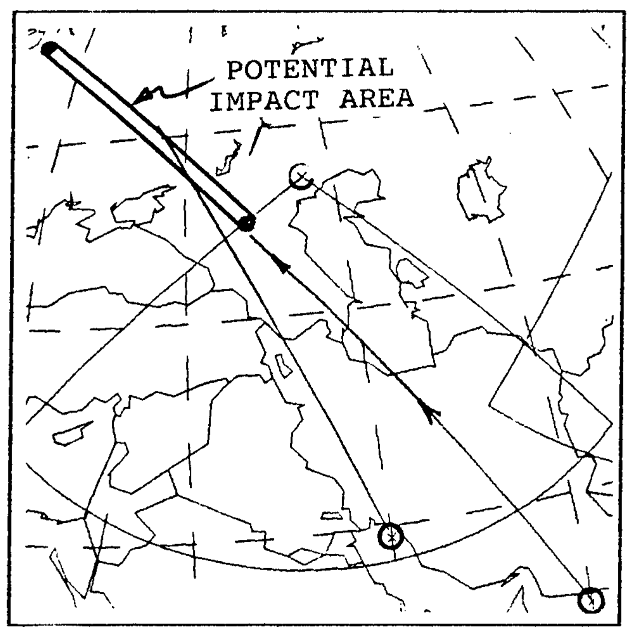

Figure 21 Russian ABM Radars

Russian perceptions would be dependent on the capabilities they would have in or near the theater. In this example of the use of boost phase intercept, we assume that the Russians have two anti-ballistic missile radars located near Astrakhan and Balkash [14]. These radars could be of the newer type (as of 1985) which are especially designed for tracking ballistic missiles, and would have capabilities for tracking satellites or other high speed objects. Long range boost phase interceptors that missed their targets would follow ballistic trajectories and cross Russia and its southern neighbors. The situation is illustrated in Figure 21. This figure shows the location and coverage of ABM radars. The ground track of long

range boost phase interceptors launched from points south of Iran are indicated. The heading is toward the northwest, and their speed is extremely high, near orbital velocity. What would the Russian operator or the Russian military leader and his analysts make of such activities? If a boost phase interceptor misses its target, its warhead could be destroyed by some sort of an explosive mechanism. If the warhead is not destroyed, then Russian radars may detect it and determine that it is aimed at them. Interceptors launched from Chah Bahar (east of the Straits of Hormuz) along an azimuth of 330 deg (the ground track to the right in Figure 21) would actually impact in Russia or in Lithuania for attempted intercepts against a DF-3 or Scud ballistic missile. Interceptors fired along this azimuth would impact somewhere between the airfield Budennovsk Northwest (44.8 deg N, 44.03 deg E) and the airfield Daugavpils Northeast (56.87 deg N, 25.88 deg E). The potential area of impact is sketched in Figure 21. If the warhead is destroyed by an explosive device, the debris will still follow the same mean trajectory. The debris generally results in a much larger radar target than does a single object. The debris might burn up during re-entry, but the Russian radar operators would observe a high speed missile aimed at them. If the radar data were extrapolated, then the predicted impact point would be on Russian territory.

Interceptors launched in an easterly direction from the northeast corner of the Mediterrean to counter Iraqi missiles raise yet another problem. These interceptors would have impact points ranging from Jodphur, India to ocean impact points near the coast of Burma. Interceptors launched westward from the Sea of Japan meant to engage North Korean ballistic missiles would travel in the direction of China and Russia. Thus, we conclude that such launches could be very provocative, and not limited to nations adjacent to the theater of operations.

OVERVIEW AND OBSERVATIONS

In this report, some concepts for implementing boost phase interception techniques for theater missile defense have been explored in a preliminary way. The exploration examined interceptor performance from a variety of launch areas. Many issues were not examined and would call for further analysis if full development were to proceed. In this overview, the issues raised by this preliminary analysis will be highlighted. Later, some preferences amongst systems and policy will be proposed.

The main reason for investigating boost phase intercept concepts is to counter third world missiles that could carry multiple munitions, thus negating many warheads and decoys with the committment of one or two interceptors. Ballistic missile payloads could consist of many submunitions, 40 or more, loaded with chemcal agents, biological toxins, or other weapons of mass destruction. A few missiles armed in this manner could easily saturate or overwhelm currently proposed terminal or midcourse theater missile defenses.

Long Range Interceptors

The long range boost phase interceptors examined in this report could be based at sea, or launched from large aircraft. In this analysis, the hostile area selected for study was large and was comprised of Iraq and Iran. The interceptor was designed to fly about 400 n mi in 100 sec so that the launchers could remain outside hostile territory. Because of the need to rapidly reach out and intercept missiles during boost phase, the average velocity of the interceptor was very high compared to that associated with a terminal or midcourse theater missile defense. When launched from a ship the missile reached velocities of about 25,000 ft/sec, and about 30,000 ft/sec when launced from a large aircraft. To provide a rapid reaction, the long range interceptor accelerated fast. The example design used here for illustration had a powered time of flight of about 14 sec. This short flight time was a result of a high thrust to initial weight ratio (40).

Assuming that there would be some time delays (up to 40 sec) to account for detection, tracking, and target designation, ballistic missiles with powered flight times of 120 sec or more could be engaged at ranges of 400 n mi or more. In this study, examples of such missiles would include the Al Husayn and the Dong Feng-3. Performance was marginal against the Scud because of its assumed shorter burning time (about 110 sec). Missiles with shorter burning times could be engaged, but only at much shorter ranges. One example of such a missile was a single stage rocket employing solid propellants. The higher thrust to initial weight ratio (3) resulted in a much shorter burn time (70 sec). Thus, long range boost phase interceptors can be countered by an

attacking missile with a short time of powered flight. In our example, the initial thrust to weight ratio was about twice that normally associated with liquid propelled rockets. If a designer chooses, there is no reason why higher thrust to weight ratios can be implemented at the inital design phase. Modifying existing missiles to provide a higher thrust to weight ratio could be complicated.

With the assumed interceptor reach of about 400 n mi, coverage of Iraq and Iran could be accomplished by three U.S. ships stationed in the easter Mediterranean Sea, in the Persian Gulf, east of the Straits of Hormuz, and one Russian ship in the Caspian Sea. If the Russians chose not to participate in this joint venture, the the northeastern part of Iran would not be covered. Missiles launched from this area could most easily attack Russia, Afghanistan, Pakistan, India, and China. Attacks on Saudi Arabia, Jordan, Egypt, and Israel would be somewhat more difficult because of the longer missile ranges needed.

Using a ship as a base for a long range (400 n mi or more) interceptor would seem preferable to employing an aircraft. The interceptors examined here had a warhead weight of 200 lbs, and a launch weight of about 10,000 lbs. The endurance and load capacity of the ship compared to that of even a large bomber was the basis for this preference.

Short Range Interceptors and RPVs

Smaller short range interceptors could be carried by remotely piloted vehicles (RPVs). These vehicles would intrude into hostile airspace. High flight altitudes, long endurance, and stealth characterize these platforms. Vehicles with such properties are being designed and tested at present. The U.S. Air Force and Navy are examining the use of manned fighters as platforms, and include the F-15 and F-14. In addition, Israel is studying PRV based boost phase interceptors to complement their terminal defense, Arrow [15].

Analyses of coverage of Iran and Iraq indicated that an interceptor with a reach of about 100 n mi would keep the number of interceptor platforms to a reasonable value, about 20. Interceptor ranges less than 100 n mi would result in the need for more platforms.

The short range interceptor examined in this analysis could weigh between 220 and 525 lbs, depending on selection of design parameters and payload weight (100 to 200 lbs). The average velocity amongst these designs was the same, about 5100 ft/sec, far less than that of the long range interceptors considered earlier. Some time delays could be accomodated in countering liquid propelled ballistic missiles. As before, solid propelled rockets would have to be attacked at shorter ranges. However,

because the RPVs would operate over hostile territory, they could be massed in the vicinity of missile launchers IF intelligence information was available. Intelligence information concerning missile launcher locations would provide leverage and might result in fewer numbers of RPVs needed, if the information is believed and assessed as being reliable by combat commanders.

Other Applications of Boost Phase Intercept for TMD

The long range interceptors could be used against ballistic missiles other than those classified as "tactical." Sea launched ballistic missiles (SLBM) and intercontinental ballistic missiles (ICBM) have much longer times of powered flight than the theater missiles considered earlier. For this reason, the engagement ranges of the sea based interceptors would be much longer than those for theater missiles. Either the U.S. or Russia might choose to employ boost phase interceptors designed for theater defense to attack and counter their opponents' strategic forces. The Russians have expressed concern about this possibility.

The present analysis indicates that the Russians could probably cover the launch area of Trident missiles with two ships. Similarly, the U.S. could possibly counter some Russian ICBMs with a single ship. These possibilities should be taken into account when both sides try to reach agreement as to the definition of and restrictions on theater missile defenses as opposed to strategic missile defenses covered by the ABM Treaty.

A Side Effect of Boost Phase Intercept in TMD

The high velocity of long range boost phase interceptors when employed in theater combat could lead to misperceptions and unwanted confusion by a number of non-participants. If a high velocity interceptor misses its target, it will continue on a high speed trajectory and land in an unintended location. If the interceptor is equipped with an explosive charge which will destroy it in case of a miss, the debris will still follow some mean trajectory. In either case, the object(s) may pass through surveillance sensors and provide an unintended cause for alarm. Several instances of this problem were noted. One, in particular, could give pause to the Russians. Boost phase interceptors operating in the Persian Gulf and firing northward would overfly and impact on Russian territory if the interceptors missed their targets.

Other Issues

The scope of this analysis was limited to examination of boost phase interceptors and their platforms for theater missile defense, and their performance. Performance parameters included speed, reach, a variety of threats, and three concepts involving kinetic kill by direct hit or hit by fragments of high explosive

warheads. Many paramenters beyond these would need definition before selection of a particular system would be considered.

Among the issues not considered are interceptor platform survival, kill effectiveness or probability of hit, means of detecting missile launches in a timely manner, missile tracking, target designation, and command and control of platforms and interceptors. Many of these issues will need resolution before any system could procede to development and deployment phases. The Department of Defense is undoubtedly examining many of these issues [15].

Some Preferences

This analysis of platform stationing and interceptor performance gives rise to a number of topics for discussion. There will be preferences by the Department of Defense, and others within the arms control community.

The longer reach of sea based interceptors may be appealing to defensive force operators. If interceptors can cover a large area such as Iraq and Iran, they would have application at shorter ranges in other theater defense scenarios. Some alternative situations could include countering missiles launched from North Korea, or perhaps from Libya. Ships can stay on station for prolonged periods of time providing a nearly continuous shield against a particular rogue nation. The high velocity of the interceptor may offer possibilities for boost phase intercepts against strategic missiles. Such potential operations do cloud the difference between "tactical" and "strategic" defenses.

Shorter range interceptors based on remotely piloted vehicles do not offer the possibility of operations against the strategic forces of the superpowers. The velocity of the shorter range interceptors is such that they are clearly intended for combat in the third world to protect allies and friends. The interceptors are much smaller and can be carried by RPVs or perhaps by manned aircraft. The intrusiveness of such systems may dictate the use of unmanned platforms. If hostile ballistic missiles are to be launched as a part of combat, such as in Desert Storm, then the short range interceptors based on stealthy platforms could provide a needed capability in terms of endurance and timing. However, if there is a desire to maintain a continuing presence before or after a period of combat, then this need would favor developing sea based platforms and long range interceptors.

Of the system concepts explored in this limited study, the author would prefer development of a boost phase interceptor that employs remotely piloted vehicles capable of operating during periods of conflict. Such a system fits well with multi-tiered

defenses, and the Israelis favor short range interceptors for this reason [15]. The interceptors based on RPVs seem less provocative to other nations outside of the combat theater. They do not have the extreme velocities and unintended capabilities associated with longer range interceptors. The greatest uncertainty about this concept is survival of the defense. Survival of the platform is crucial, but may be different for different theaters of operation. Though many system developers attempt to show that survival is no problem, experience indicates that in combat there will always be attrition. The degree of attrition cannot be estimated until more complete designs are developed, and analyses of the air defense capabilities of various third world nations are performed.

Several policy issues emerge from this analysis. We feel that the United States should not develop theater missile defense systems and deployments that might hold strategic forces by the Russians or the U.S. at risk. Theater defenses used in a way to counter strategic forces on either or both sides will decrease first strike stability and could initiate another round of arms racing. Second, the U.S. and Russia do not need to develop high performance long range theater missile defenses. Such systems will blur the distinction between strategic and theater defenses. Preferring lower performance systems in conjunction with restrictions on geographic deployment could point the way to mutual agreement, not confrontation amongst signatories to the ABM Treaty.

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